Charge Imaging of GaN Devices

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Our objective is to improve GaN-based devices by investigating deleterious effects such as surface charging and current leakage. We use scanning probe microscopy techniques that detect surface charge and bulk current leakage at the nanometer-scale. Here, we examine surface charging effects in field effect transistors (FET) which may be a reason for lower than expected radio frequency power output from nitride FETs.

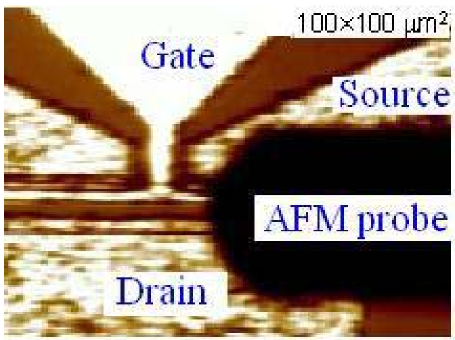

Fig. 1 Optical image of GaN FET showing locations of the gate, drain, and microscopy probe .

We have found that surface charging does occur near the gate of a FET. Following a gate pulse, electrostatic force microscopy indicates a decrease in surface potential near the gate edge (Fig 2b), likely due to tunneling of electrons from the gate into surface states and their subsequent capture. This surface charging phenomenon, which is temporary, partially depletes the channel electrons and thus decreases the drain current. We are currently investigating surface treatment methods to mitigate these charging effects and improve device performance.

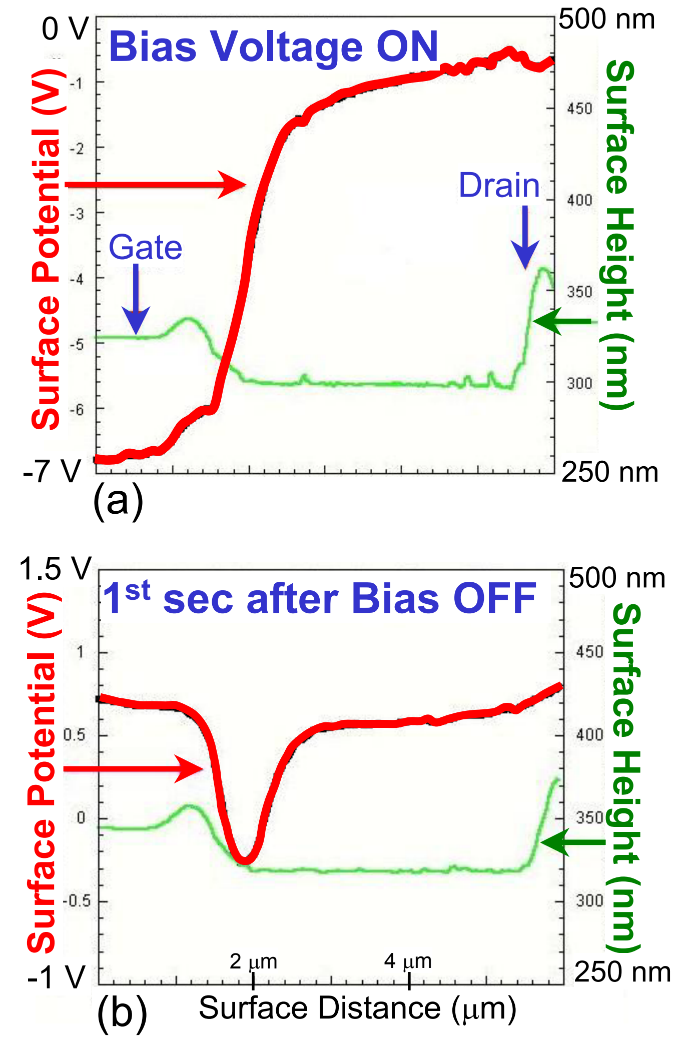

Fig. 2 AFM-EFM profile between gate and drain with (a) gate at –9 V, drain and source at 0 V, and (b) 1 s after turning off bias. The depression in potential near the gate indicates increased surface charge.

AIM OF THE PROJECT:

Currently, the high frequency power output of wide bandgap field effect transistors (FETs) is much lower than expected, due to effects such as “current collapse” and associated dispersion effects. One of the objectives of this grant is to find direct experimental evidence of surface charging in FETs that leads to such effects, and through mechanistic understanding to develop improved materials based solutions to decrease such surface charging.

RESEARCH RESULTS:

We have found that surface charging takes place near the gate of a FET. Electrostatic Force Microscopy (EFM) was used to measure the surface potential between the gate and drain region of a GaN-based FET (Fig. 2). EFM is an imaging technique that correlates surface potential with topographical features with a resolution of tens of nanometers. For the device under study, the spacing between the gate and drain was 4 microns. The surface potential was measured between the gate and drain in one second after turning off any applied biases. These biases were applied from a pulse source so that they could be turned off in a few nanoseconds. The surface potential traces showed that band bending close to the gate increased during the duration of an applied bias. This increase in band bending is caused by an increased amount of charge trapped in the surface states. The most likely reason for this trapping is the tunneling of electrons from the gate to surface states close to the gate, as detailed below.* This surface state charging phenomenon causes a partial depletion of channel electrons which in turn causes a reduction in drain current, i.e. causes current collapse.

*Two different biases were used in these studies: (1) –9 V to gate with drain and source at 0 V, and (2) –1.5 V to gate with drain at 7.5 V and source at 0 V. In the case of bias (1), no current flows through the device and therefore surface states can only be charged by tunneling from the gate. In the case of bias (2), current flows through the device and surface states could be charged both by tunneling from the gate and injection from the channel. For both biases, however, we observed a similar increase of band bending. This indicates that tunneling of electrons from the gate is responsible for surface state charging near the gate. This increased band bending returned to its equilibrium value after ~3 min.

SIGNIFICANCE OF THIS WORK

Different mechanisms and remedies have been suggested for “current collapse” in nitride-based field effect transistors. Here, we find direct evidence of surface state charging near the gate due to electron tunneling, which is a factor in current collapse. To solve this problem, we are examining methods to decrease electron tunneling and to passivate surface states.

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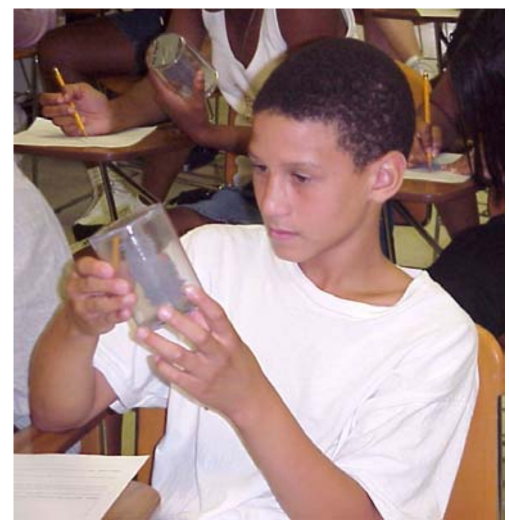
Education

This grant supports one component of a comprehensive research program that involves the growth, characterization, and device fabrication of III-nitride films.

This component concerns local surface potential and current imaging of GaN films and involves the efforts of two graduate students (Shahriar Sabuktagin, Katherine Cooper), and two undergraduates (Matt Sievert, Kabongo Ngandu). NSF funds provide partial support of the graduate students and undergraduates.

Outreach

The undergraduates involved in this grant have also been involved with outreach activities during the summer. In particular, they have helped Dr. Baski to teach physical science lessons to 200 disadvantaged students in the National Youth Sports Program held each summer at VCU.



NYSP students (left) use a generator to make an electromagnet and (right) examine how magnets affect iron filings.